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MTR-172

HF CHANNEL DATA ERROR STATISTICS DESCRIPTION (II)

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FOREWORD

This report was prepared by the Range Communications Planning and Technology Subdepartment of The MITRE Corporation, Bedford, Massachusetts, under Contract AF 19(628)-5165. The work was directed by the Range Instrument Division under the Directorate of Aerospace Instrumentation, Air Force Electronics Systems Division, Laurence G. Hanscom Field, Bedford, Massachusetts. Captain Joseph J. Centofanti served as the Air Force Project Monitor for this program, identifiable as ESD (ESRI) Task 5932.07, Range Digital Data Transmission Improvement.

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REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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Acting Director
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ABSTRACT

A description of bursts and corresponding intervals in terms of probability distribution function parameters for varying error densities is presented. This statistical data is based on the 1965 Antigua-Ascension HF digital data transmission tests conducted by The MITRE Corporation.

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HF CHANNEL DATA ERROR STATISTICS DESCRIPTION (II)

INTRODUCTION

The purpose of this report is to present the results of error measurements on an HF radio channel obtained as part of the Range Digital Data Transmission Improvement Program being conducted at MITRE. The scope of this report is limited to the presentation of descriptive statistics of error occurrences in the test transmission over an operational HF data link. The statistics presented here are designed to provide meaningful information that is useful in the design of recurrent type error control equipment implementation for improvement of channel error rate. In a previous report a presentation of descriptive statistics suitable for the design of block error correction code implementation was given. The descriptive statistics given in the previous report include the distribution functions for consecutive bits in error and error free gaps. The raw data used in generating the statistics in this report is included in MTR-171.*

The HF channel implementation consisted of a transequatorial path of approximately 3,200 miles. The RF facilities were provided by the Air Force Eastern Test Range. The digital modems used for this test were leased from Collins Radio Company. The tests were organized and performed by The MITRE Corporation. A detailed description of the test implementation is given in MTR-2 **.

A total of 14 runs of data were used to generate the descriptive channel error statistics presented herein. There are a total of 9 runs of data at 1,200 bits per second and 5 runs at 2,400 bits per second. The length of each run of data was approximately 10 minutes.

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* K. Brayer and O. Cardinale, HF Channel Data Error Statistics Description (I), The MITRE Corporation AF 19(628)-5165, Bedford, Massachusetts, 15 April 1966 (U).

** K. Brayer, R. Greim and F. Nelson, Test Plan - 1965 Antigua-Ascension High-Frequency Tests, The MITRE Corporation, AF 19(628)-5165, Bedford, Massachusetts, 2 October 1965 (U).

SECTION II

DESCRIPTION OF CHANNEL STATISTICS

ORIGIN OF THE DATA

The data which represents the effects of the channel on data transmission quality was derived from an HF link between Antigua and Ascension Island stations of the ETR. This test data was gathered over a period of time sufficient to expose the effects of diurnal variations on the channel as well as short term effects such as fading. The data used to derive the channel description presented here is selected from a total of 24 hours of data (gathered over a six-week period).

The raw data was generated in the following manner. A 52-bit test message was continuously transmitted through an HF channel from Antigua to Ascension Island. The data received at Ascension Island was then retransmitted, without regeneration, back to Antigua. The received data was then added, modulo two, to the transmitted test message after allowing for propagation and equipment delays. The modulo two adder output provides a 'one' for each bit received in error and a 'zero' for each bit received correctly. The output of the modulo two adder was recorded on magnetic tape in real time. In addition to recording the received error patterns introduced by the channel, the relevant channel conditions were also recorded for each fun of data. Such conditions as noise bursts and interference signals were monitored and recorded. The characteristics that were used in the channel description presented here specifically exclude any errors that were attributable to channel outages due to equipment failures.

The modem that was used for these tests is the Collins Radio Company Model TE-216 modem. This modem is designed for digital data transmission over HF and wire line facilities. The modem is designed to operate at data rates up to 3,600 bits per second. The unit uses 4-level phase modulation of each of 16 frequency multiplexed audio tones for 2400 bits per second data rate. For a data rate of 1200 bits per second, only 8 tones are used. The phase of each tone is changed at a rate of 75 times per second. The detection and encoding technique used in the modem permits an information rate of 150 bits per second per tone. This is accomplished using differential phase shift keying and detection. The signal detection process uses coherent differential phase shift detection technique to decode the phase modulated signal for each incoming tone. A more detailed description of the modem theory of operation is given in the Collins Radio Company Instruction Manual on the TE-216 modem.

The recorded data was processed at The MITRE Corporation computing facilities, and the data was segregated into two categories. One category is the burst which is defined as follows. A burst is a region in the data stream where a minimum specified error density is exceeded. This region is always immediately preceded and followed by a correct bit.

The other category of data is the interval, which is all the remaining data not classified as a burst. The interval is always immediately preceded and followd by an error. It should be noted that the definition permits the existence of errors in the Interval region of data, and error-free bits in the Burst region of the data.

DATA PROCESSING METHODS

As previously mentioned, magnetic tape recordings of the time sequence of errors were made in the field. These tapes were then transported to The MITRE Corporation, Bedford facilities, where they were processed through the magnetic tape conversion equipment which supplied IBM compatible tapes of the recorded errors. The data was thus placed in a form which permitted the efficient application of high speed data processing techniques.

Each individual test run was then processed to obtain the distributions of both bursts and intervals. These distributions were then processed to derive the following parameters for each selected value of Δ*.

a) Mean burst length,
b) Mean interval length,
c) Percent of intervals less than mean burst length,
d) Percent of bursts less than mean interval length,
e) Peak(s) of burst distribution and corresponding magnitude,
f) Peak(s) of interval distribution and corresponding magnitude,
g) Percentage of bursts that are longer than the immediately following intervals.

The data processing described above was performed for each run of data.

There are a total of 17 different values of minimum burst density selected for each run, with an average of 50 points for each selected value of error density Δ. Thus, there would be a total of approximately 17 x 17 distributions available.

It is impractical to present that many curves of this report, so that the previously mentioned descriptive parameters are given instead in the following sections.

DESCRIPTION OF BURST DISTRIBUTION

Definition

A burst is defined as a region of the serial data stream where the following properties hold. A minimum number of errors, M_e, are contained in the region and the minimum density of errors in the region is Δ. Both of these conditions must be satisfied for the chosen values of M_e and Δ for the region to be defined as a burst. The density of errors is defined as the ratio of bits in error to the total number of bits in the region.

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* Density of errors in a burst region.

The following properties hold for the burst. The burst always begins with a bit in error and ends with a bit in error. A burst may contain correct bits. Each burst is immediately preceded and followed by an interval in which the density of errors is less than Δ.

The burst probability density function is defined as the probability of occurrence of a burst of size N, where N is any positive integer. The burst size is measured in terms of the total number of bits in the burst. A separate burst probability density function may be determined for each pair of values of Δ and M_e.

Description

The statistical parameters of the burst probability density functions are shown in Tables I through XVII. A total of 17 runs of data were selected and the descriptive statistical parameters were tabulated here for each selected value of burst density. These are as follows:

a) Mean burst length $\bar{B}$,
b) The percentage of bursts that are less than the mean interval* length (% $B < \bar{I}$),
c) The peak(s) of the distribution, (B_p),
d) The magnitude of the peak(s) of the distribution ($/B_p/$),
e) The percentage of bursts which have a length greater than the immediately following interval length ($B/I > 1$).

The tabulated data show the mean burst length for each run increases monotonically as the burst density is decreased. This is to be expected, since decreasing the minimum burst density parameter permits longer bursts to be included from the data in the run.

The minimum number of errors in a burst has been chosen to be two (2) for all the data included here. It was found that larger values of M_e would not change the values of mean burst length significantly. However, the intervals between the bursts were found to increase drastically so that little meaningful data could be obtained for the burst to consecutive interval ratio. When a value of one (1) is selected for M_e, every error becomes a burst. Consequently, no meaningful data is obtained for this value of M_e.

DESCRIPTION OF INTERVAL DISTRIBUTION

Definition

The interval is defined as the region of the serial data stream where the following properties hold. The minimum density of errors is less than Δ, and the region begins and ends in a correct bit. An interval may contain errors. An interval is always immediately preceded and followed by a burst. Thus, each and every bit in the data stream must lie in either a burst region or an interval region.

* Defined in the following section.

The interval probability density function is defined as the probability of occurrence of an interval of length L, where L is any positive integer. The interval probability density is a joint function of both Δ and M_e.

DESCRIPTION

The statistical parameters of the interval probability density functions are also tabulated in Tables I to XVII. A total of 17 runs of data were selected and the descriptive statistical parameters for each of these runs were tabulated. Since the probability density function varies for each value of Δ, it is not practical to present these functions completely. Instead the following descriptive statistical parameters were selected and calculated for each value of burst density. These are as follows:

a) Mean Interval length $\bar{I}$,
b) The percentage of intervals less than the mean burst length ($\% < \bar{B}$),
c) The peak(s) of the distribution (I_p),
d) The magnitude of the distribution peaks(s) ($/I_p/$).

The observed behaviour of the interval distributions was analyzed for both bursty and random type error runs. It was found that the random type runs consistently displayed the following characteristic. For any given interval size, the frequency of occurrence never exceeded a value of 2, and the great majority of occurrences were single events. In contrast, runs with bursty error patterns had a high order of frequency of occurrence for several values of interval length. It would be intuitively suspected that this should be the case for bursty runs. The fact that the interval distribution rather than the burst distribution displays the distinguishing characteristic which permits separation of bursty and random type runs is sowewhat surprising however.

SECTION III

CONCLUSIONS

The mean burst length, $\bar{B}$, increases monotonically as the burst density factor Δ is decreased. This occurs because the decreased value of burst density permits longer sequences of errors to be classified as bursts.

It was found that the minimum number of errors in a burst, M_e, has no significant effect on the burst length distribution for values greater than one. However each error becomes a burst for M_e equal to one, while for values greater than 2, the corresponding interval distributions become meaningless in the sense that the distinction between the interval and burst distributions becomes blurred.

A tentative criteria for determining whether a given run is bursty or random has been found. A random run will have a very uniform interval distribution where the value of any interval size occurrence never exceeds two (2). A bursty run on the other hand will have several values of interval size where the frequency of occurrence is high (greater than 10).

Kenneth Brayer

K. Brayer

Otto Cardinale

O. Cardinale

Run No. 85 (1200 bps)

Average Error Rate 4.5×10^{-4}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I < \bar{B}$	$\% B < \bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I} > 1$
0.5	4.7	25686	7.1	100	2	5	63	7.1	11
0.4	6.6	29967	0	100	2	U	74	4.2	0
0.35	6.6	29967	0	100	2	U	74	4.2	0
0.3	6.6	29967	0	100	2	U	74	4.2	0
0.25	7.1	29966	0	100	2	U	74	4.2	0
0.2	7.3	27660	0	100	2	U	68	3.8	0
0.15	12.2	29961	0	100	2	U	60	4.1	0
0.1	18.4	18912	216	100	2	U	37	2.6	2.7
0.05	35.5	17510	0	100	2	U	25	2.4	0
0.04	37.3	16312	0	100	2	U	23	2.2	0
0.03	49.5	14938	0	100	2	U	19	2.0	0
0.02	80.7	15226	0	100	2	U	10	2.1	0
0.01	145	13691	0	100	2, 33	U	7.8	1.9	0
0.005	402	12926	0	100	33	U	5.6	1.8	0
0.001	3692	10768	22	95	U	U	2.0	2.0	12.2
0.0005	16041	11195	85	53	U	U	3.8	3.7	38
0.0001		END OF DATA							

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE I

Run No. 91 (1200 bps)

Average Error Rate 9.6×10^{-5}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	% $I<\bar{B}$	% $B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	% $\frac{B}{I}>1$
0.5	7.1	102727	0	100	U	U	16.6	14.2	33
0.4	12.2	143817	0	100	U	U	25	20	0
0.35	13.8	143816	0	100	U	U	25	20	0
0.3	15.0	143815	0	100	U	U	25	20	0
0.25	15.0	143815	0	100	U	U	25	20	0
0.2	15.0	143815	0	100	U	U	25	20	0
0.15	15.0	143815	0	100	U	U	25	20	0
0.1	16.0	79889	0	100	14, 20	U	25	11	0
0.05	21.8	71893	0	100	14, 20	U	22	10	0
0.04	50.0	71860	0	100	14, 20	U	22	10	0
0.03	50.0	65330	0	100	14, 20	U	20	9	0
0.02	50.0	65330	0	100	14, 20	U	20	9	0
0.01	50.0	65330	0	100	14, 20	U	20	9	0
0.005	50.0	65330	0	100	14, 20	U	20	9	0
0.001	2339	87844	0	100	U	U	14	12	0
0.0005	6353	74256	0	100	U	U	12	11	0
0.0001	195767	32958	100	0	U	U	33	25	66

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE II

Run No. 95 (1200 bps)

Average Error Rate 1.1×10^{-4}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\%I<\bar{B}$	$\%B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\%\frac{B}{I}>1$
0.5	3.3	79872	11	100	3	U	50	11.0	12
0.4	4.1	89856	0	100	3	U	42	12.5	0
0.35	4.1	89856	0	100	3	U	42	12.5	0
0.3	5.8	102692	0	100	3	U	50	14.2	0
0.25	7.0	89853	12	100	3	U	43	12.5	14
0.2	7.0	89853	12	100	3	U	43	12.5	14
0.15	9.3	102690	0	100	3	U	33	14.2	0
0.1	15.4	51334	0	100	17	U	23	7.0	0
0.05	27.5	55273	0	100	17	U	25	7.6	0
0.04	38.5	51312	0	100	17	U	15	7.1	0
0.03	75.9	55228	7.6	100	U	U	8.[illegible]	7.6	0
0.02	100	51255	0	100	U	U	7.7	7.1	0
0.01	325	59608	16	100	U	U	9.0	8.3	18
0.005	731	79225	0	100	U	U	12.5	11.1	0
0.001	1170	78835	0	100	U	U	12.5	11.1	0
0.0005	2926	77274	0	100	U	U	12.5	11.1	0
0.0001	150062	67173	75	66	U	U	33.0	25.0	33

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE III

Run No. 101 (1200 bps)

Average Error Rate 1.2 x 10^{-2}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I<\bar{B}$	$\% B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I}>1$
0.5	2.9	725	0	100	2	14	45	6	.30
0.4	3.2	679	0.2	100	2	14	41	5.4	.95
0.35	3.3	684	0	100	2	14	40	5.2	1.5
0.3	3.7	654	0.1	100	2	14	38	5	2.4
0.25	4.9	617	0	100	2	14	34	4.8	3.8
0.2	6.9	622	0.9	100	2	14	32	4.9	4.5
0.15	15.1	668	4	99	2	16	17	1.7	7.2
0.1	23	342	9.7	99	17	15	20	2.9	13
0.05	73	434	17	97	18	47	12.5	2.0	13
0.04	117	479	25	96	18	63	11.2	1.7	13
0.03	214	541	37	93	18	111	8.3	1.8	15
0.02	635	660	66	86	18	398	6.6	1.6	22
0.01		END OF DATA							
0.005									
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE IV

Run No. 149 (1200 bps)

Average Error Rate 8.5×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%$I<\bar{B}$	%$B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	% $\frac{B}{I}>1$
0.5	3.4	655	1.0	100	2	12	33	8.4	2.6
0.4	3.9	620	0.5	100	2	12	29	8.5	2.9
0.35	4.2	633	0.4	100	2	12	28	8.5	3.6
0.3	5.0	602	0.7	100	2	12	25	7.6	5.2
0.25	7.1	601	2.0	100	2	12	23	7.2	9.2
0.2	12	693	12	100	2	14	21	6.1	13.2
0.15	29	937	23	99	2	15	11	5.2	19
0.1	54	826	40	98	17	15	24	4.4	23
0.05	224	1552	52	96	17	63	11	1.7	16
0.04	377	1880	58	96	17	95	10	1.8	17
0.03	759	2414	59	96	17	95	7.9	2.2	16
0.02	2198	3767	58	96	16, 17	191, 223	4.1	1.6	10
0.01	31481	6075	100	94	U	U	5.2	5.0	10
0.005		END OF DATA							
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE V

Run No. 151 (1200 bps)

Average Error Rate 7.8×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%$I<\bar{B}$	%$B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	%$\frac{B}{I}>1$
0.5	3.3	782	0.5	100	2	14	43	6.0	3.3
0.4	3.9	744	0.8	100	2	12	38	6.0	4.2
0.35	4.3	764	1.0	100	2	14	38	6.0	4.3
0.3	5.2	762	1.0	100	2	14	36	5.5	5.5
0.25	7.0	753	1.5	100	2	14	33	6.0	6.7
0.2	11.3	841	6.0	100	2	14	33	7.0	8.8
0.15	24.6	1000	16	99	2	15	15	4.4	13
0.1	37.9	754	24	99	17	15	25	4.5	19
0.05	153	1218	38	98	17	63	12	2.6	17
0.04	240	1430	46	96	17	95	11	2.0	17
0.03	456	1810	50	94	17	96	9.7	1.8	17
0.02	1130	2490	56	93	17	143	5.5	1.5	17
0.01	9360	4400	81	86	2, 17	U	3.8	1.8	23
0.005		END OF DATA							
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE VI

Run No. 221 (1200 bps)

Average Error Rate 6×10^{-5}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%I < $\bar{B}$	%B < $\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	% $\frac{B}{I}$ > 1
0.5	4.3	102821	0	100	2	U	50	14.2	0
0.4	4.3	102821	0	100	2	U	50	14.2	0
0.35	6.3	102819	0	100	2	U	50	14.2	0
0.3	6.3	102819	0	100	2	U	50	14.2	0
0.25	6.3	102819	0	100	2	U	50	14.2	0
0.2	11.2	119953	0	100	2	U	40	16.6	0
0.15	14.4	119950	0	100	U	U	20	16.6	0
0.1	15.0	102812	0	100	18	U	33	14.2	0
0.05	28.4	89947	0	100	18	U	28	12.5	0
0.04	28.4	89947	0	100	18	U	28	12.5	0
0.03	28.4	89947	0	100	18	U	28	12.5	0
0.02	28.4	89947	0	100	18	U	28	12.5	0
0.01	28.4	89947	0	100	18	U	28	12.5	0
0.005	28.4	89947	0	100	18	U	28	12.5	0
0.001	737	89326	0	100	18	U	28	12.5	0
0.0005		END OF DATA							
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE VII

Run No. 223 (1200 bps)

Average Error Rate 1 x 10^{-2}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%I<$\bar{B}$	%B<$\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	% $\frac{B}{I}$>1
0.5	4.1	584	5	100	2	13	26	5	7.7
0.4	5.0	536	5	100	2	10	21	4.3	8.2
0.35	5.9	567	3	99	2	11	21	4.1	8.3
0.3	7.4	552	5	99	2	11	17	5.0	10
0.25	10.3	555	12	99	2	11	15	4.4	13
0.2	16.5	619	23	99	2	13	14	4.2	14
0.15	32.2	753	28	99	2	15	8	2.7	15
0.1	60.5	726	37	99	17	30	12	2.5	18
0.05	219	1208	47	97	18	63	7	1.3	15
0.04	349	1472	47	96	18	79	6	1.5	16
0.03	594	1772	50	97	17	U	5	0.3	18
0.02	1382	2637	47	96	34	190, 257	3	1.1	12
0.01	3014	3587	55	89	18	359, 2811	3	1.8	17
0.005	11419	4573	95	86	5	3789	4	4.4	13
0.001		END OF DATA							
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE VIII

Run No. 258 (2400 bps)

Average Error Rate 7.6×10^{-4}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%$I<\bar{B}$	%$B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	% $\frac{B}{I}>1$
0.5	2.8	14538	0	100	2	27	46	2.0	0
0.4	3.1	13326	0	100	2	30	42	4.5	0
0.35	3.2	13450	1	100	2	30	42	4.5	0
0.3	3.7	12093	1	100	2	30	37	4.2	1.6
0.25	4.8	10901	1	100	2	30	29	4.5	2.2
0.2	6.3	10578	1.5	100	2	30	25	5.1	5.1
0.15	10.5	9849	2.0	100	2	30	20	5.4	10
0.1	23.6	10561	13.0	100	2	30	18	5.1	17
0.05	89.6	9138	17.0	100	33	31	38	5.1	10
0.04	121	10088	18.0	100	33	63	28	4.9	8.5
0.03	163	10120	24.0	100	33	127	21	4.2	8.6
0.02	221	10939	27.0	99	33	127	17	4.6	10
0.01	605	16337	34.0	100	33	190	11	2.3	13
0.005	3402	28663	35.0	97	34	1054	9	4.4	11
0.001	27100	39566	63.0	90	U	U	5	4.5	9.5
0.0005		END OF	DATA						
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE IX

Run No. 264 (2400 bps)

Average Error Rate 2.9×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I<\bar{B}$	$\% B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I}>1$
0.5	2.9	3210	0.2	100	2	30	59	6.6	.44
0.4	3.1	3080	0.2	100	2	30	55	7.0	.64
0.35	3.3	3080	0.2	100	2	30	55	6.6	.85
0.3	3.7	2910	0.2	100	2	30	49	5.6	1.0
0.25	4.5	2680	0.0	100	2	30	44	5.4	1.8
0.2	5.5	2646	0.2	100	2	30	4.3	5.7	2.9
0.15	7.9	2693	0.0	100	2	30	43	5.8	3.5
0.1	17.8	2678	3.0	100	2	30	39	6.5	8.6
0.05	58.5	1668	13.5	99	33	95	25.5	5.8	18
0.04	95.8	2060	29.0	99	33	95, 159	18.4	6.3	16
0.03	164	2370	54	99	65	94	15	8.4	20
0.02	362	3330	47	97	33	94, 159	10	3.8	20
0.01	1355	5641	41	95	161	225	6.8	3.3	20
0.005	8935	9173	68	86	33, 257	U	2.5	1.3	25
0.001		END OF DATA							
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Modd
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE X

Run No. 309 (2400 bps)

Average Error Rate 4.3×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I < \bar{B}$	$\% B < \bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I} > 1$
0.5	2.8	2086	0	100	2	30	59	13.7	.87
0.4	2.9	2050	0	100	2	30	58	13.4	.14
0.35	2.9	2053	0	100	2	30	58	13.2	.14
0.3	3.2	2024	0	100	2	30	56	12.6	0
0.25	3.4	1979	0	100	2	30	54	12.3	.13
0.2	3.6	1957	0	100	2	30	53	12.1	.13
0.15	4.3	1951	0	100	2	30	53	12.0	1.5
0.1	9.4	2129	0	100	2	30	54	12.4	5.3
0.05	51.6	996	18	99	33	63	38	7.7	25
0.04	90.6	1266	27	99	33	63	23	9.8	24
0.03	179	1553	44	98	33	63	17	7.8	29
0.02	427	2153	55	96	97	191	10	5.0	22
0.01	1946	3662	53	94	193	287	7	4.6	18
0.005	10260	6795	75	91	193	1247	6	2.3	14
0.001		END OF DATA							
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XI

Run No. 315(2400 bps)

Average Error Rate 1.7×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%$I<\bar{B}$	%$B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	% $\frac{B}{I}>1$
0.5	2.7	5496	0	100	2	29	44	8.7	0
0.4	2.9	5437	0	100	2	29	43	9.0	0
0.35	3.1	5517	0	100	2	29	41	9.0	0
0.3	3.5	5087	0	100	2	29	36	8.5	0
0.25	4.5	4348	0	100	2	29	29	7	0
0.2	4.8	4100	0	100	2	29	28	6.8	0
0.15	5.3	4111	0	100	2	29	27	6.8	1.1
0.1	11.5	4681	0	100	2	30	28	7.1	7.1
0.05	55	2468	17	99	32	63	24	7.0	22
0.04	91	3168	28	99	32	64	17	6.5	18
0.03	190	4176	36	99	33	223	8.8	4.5	25
0.02	414	5879	49	99	33	159	7.0	4.3	21
0.01	2375	14805	51	95	130	159, 414	6.0	2.3	21
0.005	18806	35256	62	92	33, 66	U	7.6	3.7	19
0.001		END OF DATA							
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XII

Run No. 339 (2400 bps)

Average Error Rate 1.2×10^{-2}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%$I<\bar{B}$	%$B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	%$\frac{B}{I}>1$
0.5	3.6	486	0.4	100	2	29	31	7.5	.88
0.4	4.0	445	0.4	100	2	28	26	7.4	.84
0.35	4.2	448	0.2	100	2	27	26	7.3	.56
0.3	4.6	424	0.0	100	2	27	23	7,5	.71
0.25	5.1	339	0.1	100	2	27	21	7.0	.98
0.2	6.1	387	0.0	100	2	27	19	6.7	2.3
0.15	9.7	400	0.2	99	2	28	18	6.1	6.6
0.1	29.3	498	20.0	99	2	30	18	6.0	16
0.05	131.0	545	45.0	98	33	31	22	3.1	19
0.04	221.0	651	51.0	97	33	63	16	2.7	17
0.03	464.0	795	66.7	96	33	95, 127	12	2.4	19
0.02	1500.0	1007	83.5	94	33	127	10	2.6	21
0.01		END OF DATA							
0.005									
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XIII

Run No. 342 (2400 bps)

Average Error Rate 2.8 x 10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	%$I<\bar{B}$	%$B<\bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	%$\frac{B}{I}>1$
0.5	3.15	4206	0.0	100	2	30	39.0	6.0	0
0.4	3.55	3678	0.5	100	2	30	32.0	5.6	.76
0.35	3.60	3687	0.25	100	2	30	32.0	5.6	.51
0.3	4.00	3415	0.0	100	2	30	27.0	4.9	.71
0.25	4.70	2994	0.0	100	2	30	22.0	4.3	.41
0.2	5.40	2806	0.0	100	2	30	21.0	4.1	.39
0.15	6.90	2673	0.0	100	2	30	19.0	4.0	1.6
0.1	13.50	2687	0.56	100	2	30	15.0	3.7	5.0
0.05	48.90	1708	9.1	100	33	31	29.9	2.9	11
0.04	71.00	1909	7.9	99	33	95	22.8	2.4	8.2
0.03	115.0	2058	11.0	99	33	95	17.3	1.8	10
0.02	223.0	2361	20.0	99	33	127	15.2	1.4	10
0.01	856.0	3430	38.0	97	33	415	8.9	0.9	12
0.005	4762.0	5130	67.0	90	33	479, 1980	3.4	1.3	17
0.001			END OF DATA						
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XIV

Run No. 111 (1200 bps)

Average Error Rate 1.8×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I < \bar{B}$	$\% B < \bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I} > 1$
0.5	2.5	7936	0	100	2	U	68	2.2	0
0.4	2.6	7450	0	100	2	U	64	2.0	0
0.35	2.8	7450	0	100	2	U	64	2.0	2.1
0.3	3.3	7157	0	100	2	U	56	2.0	2.0
0.25	4.1	6403	0	100	2	U	50	1.8	1.8
0.2	5.0	6081	0	100	2	U	47	1.7	3.4
0.15	9.4	6077	0	100	2	U	35	1.7	3.4
0.1	16.5	2537	4.9	100	18	U	21	0.7	7.0
0.05	39.8	2770	0	100	18	U	15	0.8	2.3
0.04	52.4	2536	1.5	100	18	U	14	0.8	3.1
0.03	75.4	2778	6.3	100	18	U	10	0.8	5.5
0.02	114	2880	0.8	100	16	U	7.4	0.8	2.5
0.01	323	3445	4.1	99	17	U	6.3	10.3	4.2
0.005	1060	4098	19.7	97	49	U	4.3	1.4	12.9
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XV

Run No. 117 (1200 bps)

Average Error Rate 1.3×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I < \bar{B}$	$\% B < \bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I} > 1$
0.5	2.9	9599	0	100	2	U	59	4	1.4
0.4	3.1	9229	0	100	2	U	59	1.3	2.6
0.35	3.3	9349	0	100	2	U	57	1.3	1.3
0.3	3.6	8887	0	100	2	U	53	1.2	1.3
0.25	4.2	8778	0	100	2	U	52	1.2	0
0.2	4.8	8467	0	100	2	U	48	1.2	0
0.15	8.3	7993	0	100	2	U	36	1.11	0
0.1	14.6	4918	0	100	2	U	20	0.7	0.7
0.05	31.2	4333	0	100	2	U	13	0.6	2.4
0.04	39.4	4197	0.6	100	2	U	10	0.6	3.6
0.03	55.0	4132	0.6	100	2	U	7	0.6	1.2
0.02	80	3899	0	100	2/17	U	5	0.6	1.11
0.01	202	4137	0	100	2	U	5	0.6	3.6
0.005	655	4350	7.0	99	2	U	4	0.7	7.7
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XVI

Run No. 121 (1200 bps)

Average Error Rate 2.3×10^{-3}

Minimum Burst Error 2

Δ	$\bar{B}$	$\bar{I}$	$\% I < \bar{B}$	$\% B < \bar{I}$	B_p	I_p	$/B_p/$	$/I_p/$	$\% \frac{B}{I} > 1$
0.5	2.6	5370	0	100	2	U	65	0.8	0
0.4	2.8	5031	0	100	2	U	60	0.7	0
0.35	2.9	5031	0	100	2	U	59	0.7	0
0.3	3.0	4928	0	100	2	U	58	0.7	0
0.25	3.3	4611	0	100	2	U	54	0.6	0
0.2	4.4	4552	0	100	2	U	51	0.6	0
0.15	7.4	4252	0	100	2	U	39	0.6	0
0.1	13.3	2673	0	100	2	U	21	0.4	0.75
0.05	29.0	2107	0	100	2	U	9	0.3	1.2
0.04	36.4	2032	0.6	100	2	U	8	0.3	1.7
0.03	49.5	1912	0.3	100	2	U	7	0.3	1.6
0.02	81.6	1750	0.8	100	2	U	6	0.3	2.3
0.01	205	1700	1.3	99	2	U	3	0.3	5.0
0.005	851	1838	22	90	2	U	2	0.4	16
0.001									
0.0005									
0.0001									

DEFINITIONS

Δ	Burst Error Density	B_p	Mode of Burst Distribution
$\bar{B}$	Mean Burst Length	I_p	Mode of Interval Distribution
$\bar{I}$	Mean Interval Length	$/B_p/$	Amplitude of Burst Mode
I	Interval Length	$/I_p/$	Amplitude of Interval Mode
B	Burst Length	U	Uniform Distribution

TABLE XVII

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

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3. REPORT TITLE

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13. ABSTRACT

A description of bursts and corresponding intervals in terms of probability distribution function parameters for varying error densities is presented. This statistical data is based on the 1965 Antigua-Ascension HF digital data transmission tests conducted by The MITRE Corporation.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
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SYSTEMS AND MECHANISMS						
Data Transmission Systems						
Multichannel Radio Systems						
Voice Communication (HF) Systems						
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SUBJECT: Review of Technical Document

TO: ESTI

Identification: ESD-TR-66-107, HF Channel Data Error Statistics Description (II)

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